

ON THE POSSIBILITY OF CONSTRUCTING A THIN-LAYER MODEL OF THE TRANSITION REGION FROM THE MANTLE TO THE EARTH' S CORE

GEOPHYSICS

1968

SovietRxiv

View the original and related papers at <https://sovietrxiv.org/items/ru-196801.61637>

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.

Abstract**Full Text**

UDC 550.34+551.1

GEOPHYSICS

I. S. BERZON, S. D. KOGAN, I. P. PASECHNIK

**ON THE POSSIBILITY OF CONSTRUCTING
A THIN-LAYER MODEL OF THE TRANSI-
TION REGION FROM THE MANTLE TO THE
EARTH' S CORE***(Presented by Academician M. A. Sadovskii, 16 III 1967)*

In (1-5, 10) and other works, the incompatibility has been shown between experimental data on the dynamic characteristics of reflected waves of various classes and the theoretical data obtained for some of the simplest models of the mantle-outer core boundary of the Earth. In the calculations it was assumed that the jump in density at this boundary lies within the limits $1 \leq \rho_2/\rho_1 \leq 2$ (9).

The totality of the available data shows that representation of the mantle-core boundary as a boundary between two half-spaces—elastic and liquid, elastic and elastic-viscous, or two elastic ones—gives values of the reflection coefficients and of their frequency dependences that differ from those observed. Apparently, to explain the experimental data it is necessary to consider another class of models. One of the possible models that make it possible to explain the noted differences between observed data and theoretical calculations is a thin-layer model of the transition region from the mantle to the core. The reflection coefficients of waves from a thin layer or a packet of thin layers, owing to interference, may in a certain frequency range exceed by several times the reflection coefficients from the boundaries of two half-spaces with the same differences in the parameters of the media ((11-13) and others). In this connection, the amplitudes of waves reflected from various models of thin layers may also exceed the amplitudes of waves reflected from the boundary of two half-spaces.

Below are given some data on the dynamic characteristics of the waves P_{cP} and S_{cS} , which can be explained on the basis of a thin-layer model of the transition region from the mantle to the core.

Wave P_{cP} . For the wave P_{cP} a combination of the following two features has been noted: 1) the periods T of the P_{cP} waves are smaller than the periods of the P waves. Data obtained in earthquake recordings (2) showed an average difference of 7% (according to the results of 121 determinations). In explosions the differences reach an even larger value, 15-20% (3, 5). 2) The ratio of the

amplitudes of the vertical components W of the displacement of the waves P_{cP} and P exceeds the theoretical values for the boundary of elastic and liquid half-spaces, under the condition that $\rho_2/\rho_1 \leq 2$.

Since, in shallow (1) and deep-focus (2) earthquakes and in explosions (3, 5), analogous regularities were obtained both on short-period and on long-period instruments, we presented the entire set of observed data $(W/T)_{P_{cP}}/(W/T)_P$ from works (1-3, 5) in one figure (see Fig. 1). From all the data (155 observations), by averaging in a 5-degree interval, an averaged curve was constructed with the corresponding standard deviations. The theoretical curve (7) was calculated without taking absorption into account. The theoretical curves from works (2, 8) in the range of epicentral distances $20^\circ < \Delta < 80^\circ$ differ little from that shown. It is clear from the drawing that the values on the averaged curve exceed the theoretical values severalfold, and that on it there is no tendency toward a decrease in the amplitude ratio at $\Delta < 40^\circ$

and $\Delta > 75^\circ$, as on the theoretical curve. The observed discrepancies between the experimental and theoretical curves can apparently be explained above all by differences in the reflection coefficients themselves at the core boundary, since there are no grounds for a substantial change in the divergence and conversion functions. Taking absorption into account, evidently, cannot completely remove this discrepancy.

The dependence of the reflection coefficient, determined from experimental data, on the epicentral distance, $K_{P_{cP}}^{\text{expt}} = K_{P_{cP}}^{\text{expt}}(\Delta)$, can be determined from the approximate formula

$$K_{P_{cP}}^{\text{expt}} = K_{P_{cP}}^{\text{theor}} M T_{P_{cP}}/T_P,$$

where

$$M(\Delta) = \left[(W/T)_{P_{cP}} : (W/T)_P \right]^{\text{expt}} : \left[W_{P_{cP}} : W_P \right]^{\text{theor}}$$

is the ratio (curve *III*) of the experimental (*II*) and theoretical (*I*) curves; $K_{P_{cP}}^{\text{theor}} = K_{P_{cP}}^{\text{theor}}(\Delta)$ are the reflection coefficients adopted in the theoretical calculation (curve *IV*). The values $K_{P_{cP}}^{\text{expt}} = K_{P_{cP}}^{\text{expt}}(\Delta)$ (curve *V*) in the range from 25 to 75° are close to unity. The values obtained for $\Delta < 25^\circ$ and for $\Delta > 80^\circ$ are apparently inaccurate because of the small amount of data. We note that for $\Delta > 80^\circ$ overlapping of the P_{cP} and P waves is possible, since the difference between their arrivals is less than 6 sec. The combination of the obtained values $K_{P_{cP}}^{\text{expt}} \approx 1$ with the values of the P_{cP} period, noted in item 1 as smaller in comparison with P , permits the supposition that at the boundary of the mantle and the core there is a thin layer (or packet of layers) with an increased velocity of propagation of longitudinal waves. As is known, the modulus of the reflection coefficient of longitudinal waves from such a layer or packet, at angles of incidence exceeding

Figure 1

Figure 1: Figure 1

Figure 2

Figure 2: Figure 2

Fig. 1. Comparison of experimental and theoretical reflection coefficients of the P_{cP} wave. *I*—the theoretical curve of the ratio $(W/T)_{P_{cP}} : (W/T)_P$ from [7]; *II*—the curve averaging the experimental values of the ratio $(W/T)_{P_{cP}} : (W/T)_P$, obtained: *a*—from earthquakes [1, 2]; *b*—from underground nuclear explosions [3, 5]; *c*—values of $(W/T)_{P_{cP}} : (W/T)_P$ averaged over a 5-degree interval of epicentral distance, and their standard deviations; *III*—the ratio of the averaged experimental (*c*) and theoretical values

$$M(\Delta) = \left[(W/T)_{P_{cP}} : (W/T)_P \right]^{\text{expt}} : \left[W_{P_{cP}} : W_P \right]^{\text{theor}} ;$$

IV—the theoretical curve of the reflection coefficient $K_{P_{cP}}^{\text{theor}} = K^{\text{theor}}(\Delta)$ from [6]; *V*—the experimental curve of the reflection coefficient $K_{P_{cP}}^{\text{expt}} = K^{\text{expt}}(\Delta)$

limiting value, increases rapidly with frequency at low frequencies, when $l/\lambda < 0.25$ (l is the thickness of the layer, λ is the wavelength in it), and approaches unity at higher frequencies (^{11–13}). This may cause the maximum of the spectrum of the P_{cP} wave to shift into the region of higher frequencies and may produce large values of its amplitudes. The possibility of the existence of a thin layer with an increased velocity of longitudinal waves is not contradicted by the fact that the observed travel time of the P_{cP} wave is smaller than according to the Jeffreys–Bullen tables (^{3,5,14}).

The data obtained are insufficient for estimating the parameters of the thin layer—the velocity of propagation of longitudinal waves in it and its thickness.

Fig. 2. Reflection coefficients $K_{S_{cS}} = K(f)$ of transverse waves (*SV*) from the core, computed from the spectra of multiply reflected waves S_{cS} and sS_{cS} (^{16,17}). **a:** *I*—averaged curve computed from two pairs of amplitude spectra of the waves $S_{cS}3 - S_{cS}2$ and $sS_{cS}3 - sS_{cS}2$, recorded at the Antofagasta station during the earthquake in Chile on 8 XII 1962; *II*—curve computed from the amplitude spectra of the waves $S_{cS}3 - S_{cS}2$ and $sS_{cS}3 - sS_{cS}2$, recorded during the Mexican earthquake at the Arequipa station; *III*—theoretical curve $K_{S_{cS}}^{\text{theor}} = K^{\text{theor}}(f)$ for the model (Fig. 2) of a thin layer at the boundary of the Earth's mantle and core.

For this it is necessary to obtain the dependence of the reflection coefficient of longitudinal waves from a thin layer at smaller epicentral distances. The frequency dependence of the reflection coefficient is expressed most clearly when

the wave is incident on the layer at nearly normal incidence. We do not know of any data on the recording of the P_{cP} wave at such small epicentral distances.

The S_{cS} wave. For the S_{cS} wave there are a few data obtained in ^(15–17) at small epicentral distances (6–12°). We used records of multiply reflected S_{cS} waves of type SV to determine the frequency dependence of the reflection coefficient of transverse waves from the mantle–core boundary. Since waves of the second and third multiples were used, the incidence on the boundary may be regarded as practically normal. To determine the dependence $K_{S_{cS}}(f)$, the records presented in ^(16,17) were digitized and spectra were determined from them. The determinations were made several times with changes in the interval selected on the record, and good repeatability of the amplitude spectra was obtained in the frequency band in which the amplitudes of the spectral components are not less than 5–7% of the maximum amplitude. From the amplitude spectra, the dependences of the modulus of the reflection coefficient $K_{S_{cS}} = K(f)$ were computed without allowing for absorption in the mantle, by the approximate formula

$$K_{S_{cS}}(f) = \frac{Q_{S_{cS}3} 6H - h}{Q_{S_{cS}2} 4H - h},$$

where Q are the moduli of the amplitude spectra of the various waves, H is the depth of the Earth's core, and h is the focal depth.

The results of determining the dependence $K_{S_{cS}}(f)$ from the experimental data are shown in Fig. 2. These data are very few, and, naturally,

one cannot base the construction of a model on them. However, certain features of the curves $K_{S_{cS}}(f)$ show that the assumption of a thin-layer model for the region of transition from the mantle to the core is admissible, and in further work it is important to refine them. These include, first of all: 1) the oscillatory character of the curve $K_{S_{cS}}(f)$ and, in particular, the presence of minima at $f \approx 0.05$ – 0.06 Hz; 2) the nonmonotonic decrease of the reflection coefficient with frequency in the low-frequency range (at $f < 0.03$ Hz). The second of the noted features indicates the inadequacy of a model consisting of a simple transition layer for the velocities v_s . The observed form of the curve is possible if in the transition region there are no fewer than two transition layers with different signs of the velocity gradient (or of the product ρv_s), or a combination of transition layers with first-order discontinuity boundaries. An example of a model for which the frequency dependence of the reflection coefficient agrees qualitatively with the experimental one is given in Fig. 2 (curve III). Of course, this should be regarded not as a model of the transition region, but only as one of the examples showing the possibility of a search within the class of thin-layer models.

Methodological remarks. To clarify the possibility of constructing a thin-layer model and determining its parameters, it is necessary, first of all, to obtain

reliable initial experimental data from which the dependence on frequency of the modulus and phase of the reflection coefficients of waves of various types can be obtained. For this it is necessary: 1) to organize special investigations in seismic regions to record reflected waves of various types at small angles of incidence on the core; 2) in observations both in the epicentral region and at large distances, it is very important, as far as possible, to extend the operating band of the frequency dependences obtained for the reflection coefficients of waves of various types. For this it is necessary to obtain records both on broadband and on filtering equipment.

It is important to obtain frequency dependences of the reflection coefficients for different types of waves, since the thin-layer model of the region of transition from the mantle to the core may be different for P and S waves.

The authors express their gratitude to A. M. Polikarpov for assistance with the calculations.

Schmidt Institute of Physics of the Earth,
Academy of Sciences of the USSR

Received
10 III 1967

CITED LITERATURE

1. S. T. Martner, *Bull. Seismol. Soc. Am.*, **40**, No. 2 (1950).
2. K. Ergin, *ibid.*, **43**, No. 1 (1953).
3. Goetz G. R. Buchbinder, *ibid.*, **55**, No. 2 (1955).
4. V. N. Zharkov, *Izv. AN SSSR, ser. geofiz.*, No. 11 (1964).
5. S. D. Kogan, *Izv. AN SSSR, ser. Fizika Zemli*, No. 3 (1968).
6. S. W. Dana, *Bull. Seismol. Soc. Am.*, **34**, No. 4 (1944).
7. S. W. Dana, *ibid.*, **35**, No. 1 (1945).
8. E. W. Carpenter, *Proc. Roy. Soc., Ser. A*, **290**, No. 1422 (1966).
9. M. S. Molodenskii, *Tr. Geofiz. inst. AN SSSR*, No. 26 (1955).
10. L. M. Balakina, A. V. Vvedenskaya et al., *Izv. AN SSSR, ser. Fizika Zemli*, No. 8 (1966).
11. I. S. Berzon, A. M. Epinat'eva et al., *Dynamic Characteristics of Seismic Waves in Real Media*, Izd. AN SSSR, 1962.

12. N. G. Mikhailova, B. S. Pariiskii, M. V. Saks, *Izv. AN SSSR, ser. Fizika Zemli*, No. 1 (1966).
13. L. I. Ratnikova, A. L. Levshin, *Izv. AN SSSR, Fizika Zemli*, No. 2 (1967).
14. S. D. Kogan, *Izv. AN SSSR, ser. geofiz.*, No. 4 (1960).
15. F. Press, *Science*, **124**, 1204 (1956).
16. R. L. Kovach, L. Don Anderson, *Bull. Seismol. Soc. Am.*, **54**, No. 6 (1964).
17. R. L. Kovach, L. Don Anderson, *Proc. Nat. Acad. Sci. U. S. A.*, **51**, No. 2 (1964).

Note: Figure translations are in progress. See original paper for figures.

Source: Math-Net.Ru and CyberLeninka. Machine translation. Verify with the original.